NASA-CR-200671

PROGRESS REPORT

Period
July 1994 to December 1995

NASA Grant NAG 52293
UMCP 01-5-26161

Biospheric Dynamics in the Boreal Forest Ecotone

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Progress Report for BOREAS Project
NASA grant number NAG 52293
UMCP 01-5-26161

March 14, 1996

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Summary: We are moving steadily towards our ultimate goal of modeling net primary production (NPP) of the boreal forest using the production efficiency concept in GLObal Production Efficiency Model (GLO-PEM). We have focused our attention on estimating the various inputs needed to run GLO-PEM using remotely sensed data from the Advanced Very High Resolution Radiometer (AVHRR). First, we determined that the georeferencing of AVHRR images for BOREAS would not diminish the effectiveness of our models. We then estimated surface variables such as surface temperature, air temperature, atmospheric water vapor, and surface wetness which are required by GLO-PEM. We have achieved great success in estimating air temperature and surface temperature. Estimation of atmospheric water vapor has been more difficult, however, we have recently attained promising results. Surface wetness has been the most difficult variable to estimate and will require additional work this next year.

Introduction

The effective use of the Global Production Efficiency Model (GLO-PEM) (Prince et al., 1995) to predict net primary production at global scales requires distributed surface temperature, air temperature, vapor pressure deficit and soil moisture data. Meteorological inputs to GLO-PEM need to be obtained at the same resolution as the vegetation parameters in order to capture variability caused by the landscape. This is especially true for surface skin temperature and surface wetness which can vary over tens of meters. Air temperature varies more slowly but our studies have shown that it exhibits spatial variability greater than can be detected by ground-based meteorological stations.

Satellites have the capability to extract environmental variables over large areas at high spatial resolution. The AVHRR is ideal because its polar orbit allows the instrument to pass over each location twice daily, once on an ascending orbit and once on a descending orbit. Its large scan angle allows the AVHRR to view large swaths of the surface each orbit. However, far off nadir data is distorted due to the instrument's large field of view.

We have used empirical techniques to extract surface variables from AVHRR data for the Boreal Ecosystem-Atmosphere Study (BOREAS). We will discuss the progress we have made towards comparing the satellite derived variables with ground measurements from the extensive automatic meteorological station (AMS) network at BOREAS. But first, we will discuss validation of the geoprocessing performed on the AVHRR images for BOREAS.

Validation of GeoComp Processing

The Canada Centre for Remote Sensing (CCRS) has developed the Geocoding and Compositing System (GeoComp) to process AVHRR local area coverage (LAC) images and is responsible for calibrating and georeferencing AVHRR-LAC images for BOREAS. GeoComp was designed to calibrate daily AVHRR images and to register the images to a standard map projection. The various data resolutions present in the AVHRR-LAC images are mapped to a common 1 km^2 grid for the BOREAS study region. There was concern that the mapping, particularly the resampling, performed by the GeoComp system would alter the data, possibly rendering it unusable in the modeling studies we are planning.

Four of the 34 images provided by CCRS for BOREAS, July 21, 23, 24 and 25, were chosen to validate the GeoComp mapping routine. These four images represent clear weather and have different satellite view angles due to the progression of the satellite's orbit. The corresponding original AVHRR-LAC, level 1b, images were obtained from the EROS Data Center in Sioux Falls, South Dakota. Calibration of the raw AVHRR images was carried out in similar fashion to that used by GeoComp. Atmospheric corrections were not applied to either set of images.

We tested the GeoComp system on a pixel by pixel basis and for 9 by 9 arrays of pixels. These comparisons showed that GeoComp processing retained the spatial integrity of the data. The ultimate test of the GeoComp system is the validation of the contextual models with data from the 24 BOREAS meteorology stations. The output air temperature from the GeoComp and raw AVHRR images were compared with observed values from the BOREAS AMS (Fig. 1). Pixels with large satellite look angles greater than 45° were removed because the contextual analysis approach fails for far off nadir pixels. Raw AVHRR and GeoComp processed images produced similar results for air temperature with correlation, R^2, of 0.66 and 0.7 respectively. Both images have a warm bias with root mean squared error, RMSE, of 3.5 K. There seems to be no evidence that GeoComp, resampled, images degrade the information content or provide information worse than level 1b data.

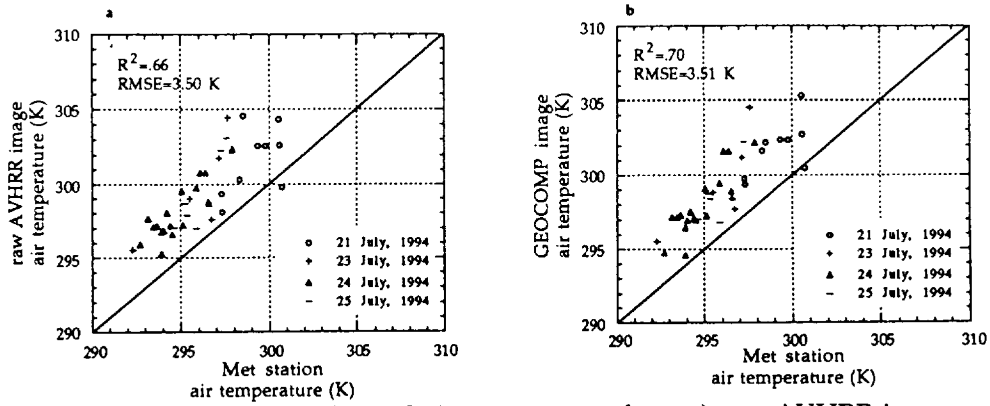

Fig. 1 Comparison of satellite derived air temperature from a) raw AVHRR images and b) GeoComp processed images with ground observations

Inputs to GLO-PEM

Surface Temperature

Satellite estimated surface temperature, Ts, was derived from channels 4 and 5 using the split window approach by Price (1983, 1984).

$$T_s = T_4 + 3.33(T_4 - T_5) \tag{1}$$

where T4 and T5 are the radiant temperatures from AVHRR channels 4 and 5, respectively. Figure 2 shows a comparison between surface temperatures estimated from (1) with measurements using Everest model 4000 infrared radiative thermometers (IRT's) at eight of the Saskatchewan Research Council's (SRC) meteorological stations. The equation tends to estimate surface temperature very well, however, it overestimates surface temperature on average by 1.8 K. This is well within the 3 K uncertainty that can be present in satellite surface temperature estimates (Cooper and Asrar, 1989).

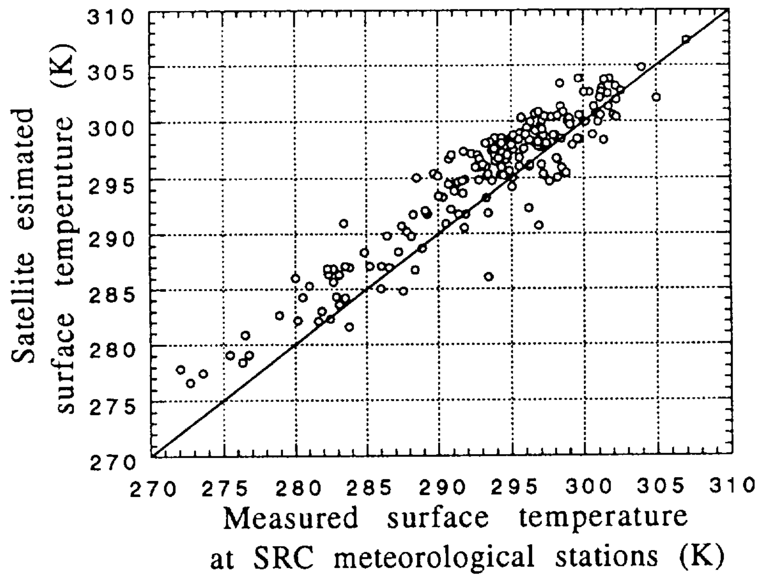

Fig. 2 Comparison of surface temperature estimated from AVHRR channels 4 and 5 using Price's equation and measured by infrared thermometers mounted ten meters above the site canopies.

Air Temperature

We used the temperature/vegetation index (TVX) to investigate the spatial distribution of surface temperature within the boreal ecosystem and estimate shelter height air temperature (Goward et al., 1994). The fundamental basis of the TVX model is that surface temperature and vegetation cover, NDVI, are closely correlated. Bare surfaces tend to have hot temperatures while closed vegetation canopies tend to be cooler. Surface temperature was derived from the Price equation as described above. NDVI was calculated from AVHRR channels 1, visible, and 2, near infrared.

$$\mathrm{NDVI} = \frac{(\text{channel } 2 - \text{channel } 1)}{(\text{channel } 2 + \text{channel } 1)} \tag{2}$$

A 9 by 9 pixel moving window was used to calculate the TVX air temperature from AVHRR images. A least squares regression was fit between surface temperature and NDVI, and the regression was extended to an NDVI of 0.7 corresponding to an infinitely thick canopy. The value for an infinitely thick canopy used for BOREAS is lower than the value used by Goward et al. (1994) because channels 1 and 2 were not atmospherically corrected for water vapor in this study. Applying atmospheric correction would result in the need to use a different infinite canopy NDVI, however, would not change the results significantly.

Table 1 shows some examples of the TVX approach. Agricultural areas, Rosetown and Saskatoon, tend to have more negative slopes than forested regions, southern study area-old aspen (SSA-OA) and northern study area-old jack pine (NSA-

OJP). The range in slopes of -3.3 to -15.2 is less negative than the TVX slopes documented in other studies (Nemani et al., 1989; Smith et al., 1991; Prihodko, 1992; Goward et al., 1994). There are several possible explanations. The low sun angles of the BOREAS study region heat the ground less than in more southern locations reducing the thermal contrast between vegetated and bare surfaces. Also, the surface tends to be very moist which causes bare ground and vegetated surfaces to have similar temperatures.

Table 1 Slope, intercept and estimated air temperature from the TVX regression. Estimated air temperature is compared with observations from the meteorology stations at Rosetown, Saskatoon, SSA-OA, and NSA-OJP.

Station	Slope (S)	Intercept (I)	TVX estimated temp. (K)	Measured temp. (K)
Rosetown	-15.2	310.2	299.6	302.1
Saskatoon	-14.6	308.3	298.1	299.5
SSA-OA	-3.3	297.6	295.3	297.1
NSA-OJP	-7.3	297.5	292.4	294.2

The TVX technique does an excellent job at estimating air temperature (Fig. 3). Measured air temperature for the BOREAS meteorological stations varied over a 35 degree range. The actual range between the spring and summer seasons was higher, but the points examined here are the ones with clear skies when the surface was being warmed. The values have a good 1 to 1 fit with a correlation of 80%, however, TVX averages higher air temperatures by 2.4 K. Prihodko (1992) found a similar bias of 4.2 K comparing air temperature with FIFE data.

There are many explanations why the estimated air temperature was consistently higher than observations. The TVX calculation itself has uncertainty in the NDVI value that is chosen for the saturated canopy. As stated above, another bias comes from the estimated surface temperature which is overestimated by 1.8 K on average.

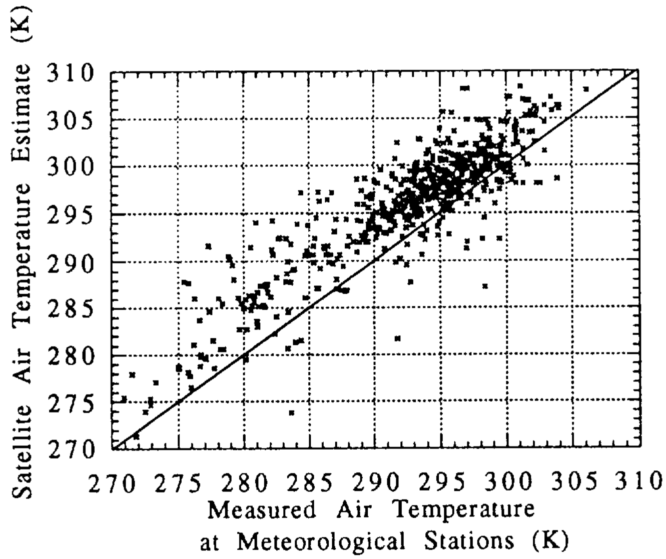

Fig. 3 Comparison of satellite estimated air temperature from the TVX approach with shelter height air temperature measured at BOREAS meteorological stations.

Atmospheric Water Vapor

We attempted to estimate atmospheric water vapor using a contextual technique (Goward et al. 1994). We regressed channels 4 and 5 of the AVHRR data taking the slope of the regression as an indication of total column water vapor. We achieved only marginal results using this technique.

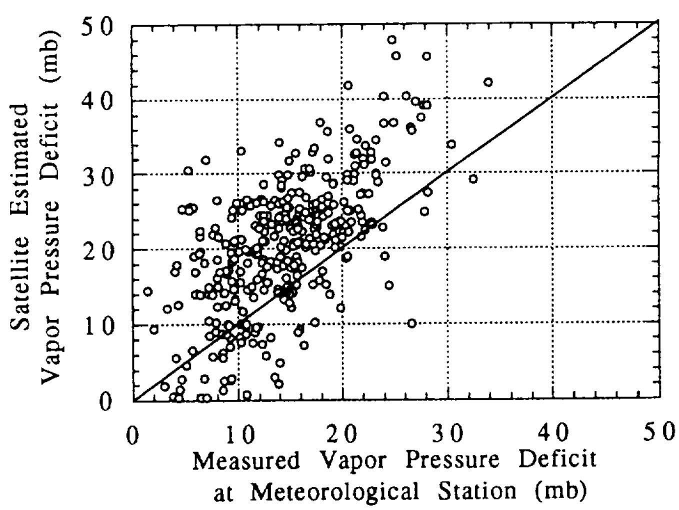

Fig. 4 Comparison of vapor pressure deficit estimated from satellite and measured at the meteorological station.

We had better results using the radiative transfer model Modtran and atmospheric profiles from radiosondes (Prince et al. 1995) to estimate vapor pressure deficit. Vapor pressure deficit controls carbon assimilation in GLO-PEM. Figure 4 shows comparison of vapor pressure deficit using remotely sensed channels 4 and 5 and surface temperature with Modtran. Total column water vapor was retrieved from the satellite data input to Modtran. Then, water vapor was scaled to the ground using an equation by Smith (1966). The comparison is encouraging, however, there appears to be much work needed before reliable estimates are possible.

Future Work

We are continuing improving our estimates of vapor pressure deficit and surface wetness from AVHRR data. Surface wetness needs the most work, and we will investigate possible modeling techniques to extract it from the data. Our next step, under the present grant, is run GLO-PEM for the summer of 1994 using the input atmospheric data. Comparison of GLO-PEM with carbon estimates will help determine GLO-PEM's accuracy in the boreal forest.

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